UNCLASSIFIED

AD NUMBER
ADB016387
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; 19 OCT 1976. Other requests shall be referred to Naval Weapons Center, China Lake, CA 93555.**
AUTHORITY
NWC ltr, 10 May 1977

THIS PAGE IS UNCLASSIFIED

NWC TP 5909

Feasibility Study of a FLIR/Imaging Seeker System

by
Jeffrey D. Grossman
Weapons Systems Analysis Division
Systems Development Department

JANUARY 1977

Distribution limited to U.S. Government agencies only; test and evaluation; 19 October 1976. Other requests for this document must be referred to the Naval Weapons Center.

Naval Weapons Center
CHINA LAKE, CALIFORNIA 93555

Naval Weapons Center

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

R. G. Freeman, III, RAdm., USN . . . . Commander
G. L. Hollingsworth . . . . Technical Director

FOREWORD

This technical report documents work conducted at the Naval Weapons Center (NWC) between July 1975 and June 1976. It was conducted under the auspices of the Night Attack Program Office of NWC, Task No. WTW32.

This report was reviewed for technical accuracy by W. G. Hueber, J. Seibold, and R. A. Erickson. It is released at the working level for information purposes only.

Released by
M. M. ROGERS, *Head*
Systems Development Department
5 October 1976

Under authority of
G. L. HOLLINGSWORTH
Technical Director

NWC Technical Publication 5909

Published by . . . . Technical Information Department
Manuscript 2362/MS-B0371
Collation . . . . Cover, 17 leaves
First printing . . . . 195 unnumbered copies

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	14 NWC-TP-5909
2. GOVT ACCESSION NO.	
3. RECIPIENT'S CATALOG NUMBER	9
4. TITLE (and Subtitle)	6 Feasibility Study of a FLIR/Imaging Seeker System.
5. TYPE OF REPORT & PERIOD COVERED	A summary report.
6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s)	10 Jeffrey D. Grossman
8. CONTRACT OR GRANT NUMBER(s)	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	Naval Weapons Center China Lake, CA 93555
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
11. CONTROLLING OFFICE NAME AND ADDRESS	Naval Weapons Center China Lake, CA 93555
12. REPORT DATE	11 Jan[redacted]y [redacted]77
13. NUMBER OF PAGES	32
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	12 33p.
15. SECURITY CLASS. (of this report)	UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	

16. DISTRIBUTION STATEMENT (of this Report)

Distribution limited to U.S. Government agencies only; test and evaluation; 19 October 1976. Other requests for this document must be referred to the Naval Weapons Center.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Human Factors
Target Acquisition
FLIR Search Set
Air-to-Ground Search

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

See back of form.

DD FORM 1473, 1 JAN 73 — EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

403019

1/B

(U) *Feasibility Study of a FLIR/Imaging Seeker System*, by Jeffrey D. Grossman. China Lake, Calif., Naval Weapons Center, January 1977, 32 pp. (NWC TP 5909, publication UNCLASSIFIED.)

(U) A three-part study was performed to determine the conditions under which an aircrewman can use a FLIR search set and an imaging seeker. The flight geometry and system characteristics that result in these conditions were also delineated. The three parts of the study included: (1) an analysis of the time available to perform the tasks required of an operator; (2) a review of research on the time required to perform these tasks with a fixed position FLIR; and (3) an experimental evaluation of the time required using a ground-stabilized, slewable FLIR.

CONTENTS

ACKNOWLEDGMENT

Carol Burge assisted with the analysis, and Roy Dale Cole designed the nomograph presented in this report. John J. Murphy designed and built the electronics.

SUMMARY

Airborne forward-looking infrared systems (FLIRs) are used by attack aircraft to locate and identify ground targets at night. Although these imaging systems have reached operational status, older, standard weapons must still be used with them. Feasibility studies are now being conducted to determine the desirable characteristics of weapons specifically designed to be used at night with the FLIR systems. This report presents the results of analyses and simulator experiments conducted to provide data on the human factors affecting the design of such weapons systems.

The weapon system configuration considered in this report was a FLIR search set coupled to an imaging IR seeker. Two FLIR configurations were considered. These were a fixed line-of-sight FLIR and a slewable FLIR. In the fixed mode the operator saw a moving scene on the display; it was an oblique view of the terrain moving from the top of the display to the bottom. The slewable FLIR operated in a "series-of-stills" mode produced by "nodding" the FLIR at a rate determined by the aircraft's altitude and velocity so that a ground-stabilized image was produced on the display.

The imaging IR seeker had a display similar to the FLIR except that it had a poorer image quality. The seeker line of sight was slaved to the FLIR line of sight. The operator's tasks were to find the target in the FLIR display, switch the display from FLIR imagery to seeker imagery, and lock on to the target.

The key variable that determines the operator's ability to use a FLIR successfully is the time available. The time available to use a fixed FLIR is determined by the altitude and velocity of the aircraft, the field of view of the FLIR, its depression angle, and slewing capabilities. This report presents equations and a nomograph which can be used to determine the time available from these variables. For example, for an aircraft flying at 200 knots, 3,000 feet above the ground with a 2-degree fixed FLIR pointing 15 degrees below the horizontal plane, 4.6 seconds are available to the operator while the target passes through the field of view.

Experimental results from a fixed FLIR simulation study are described in the report; they indicate that the target should take about 5 seconds to move through the field of view to insure that the operator can successfully switch to an imaging FLIR and obtain a lock-on.

The report also describes a simulation experiment conducted with a slewable FLIR in the series-of-stills mode. Neither the amount of terrain clutter nor the amount of FLIR/seeker misalignment affected

operator performance; the ratio of the resolution of the FLIR to the resolution of the imaging seeker was a critical variable. When the FLIR resolution was about 1.5 times better than the seeker resolution, the operator required about 7 seconds to obtain a lock-on, and he was able to lock on to all of the targets. However, when the resolution ratio was 3.0, 10.3 seconds were required and lock-on was obtained in 91% of the cases.

The performance data presented in this report can be used to estimate the effectiveness of hypothetical systems. For example, if 10 seconds are available to find the target, lock on, and launch a missile, the success rate would be 88% with a nonimaging seeker (no display switching), but only 65% with an imaging seeker whose resolution is one-third that of the FLIR.

INTRODUCTION

Currently, the capability of Navy aircraft to attack targets at night is extremely limited. However, with the advent of high-resolution, forward-looking infrared (FLIR) sensors, night attack with a variety of weapons against a broad spectrum of targets will become feasible.

One potential type of weapon that may be used is an air-to-surface missile that would incorporate an imaging seeker in order to enable the operator to aim it accurately and to verify lock-on information. Another approach would utilize a nonimaging seeker, aimed by the search set through automatic boresight alignment to reduce possible misalignment between the sensor and seeker. An imaging seeker enables the operator to see any discrepancy between the target and the aimpoint and to correct it by updating the aimpoint. However, given the flight parameters of weapon delivery tactics, the system operator may encounter some time-stress in transitioning from the FLIR to the seeker and improving upon the aimpoint. The additional time required to complete the transitioning tasks could, in fact, be more than the time available.

OBJECTIVES

The objective of this study was to evaluate the concept of using an imaging seeker coupled with a FLIR search set for night attack. The flight geometry and system characteristics concomitant with such a system were delineated. The specific tasks that were completed included:

1. An analysis of the time available as a function of system characteristics, flight geometry, and mode of operation.

2. A review of past research on the time required for operation of an imaging seeker system with a fixed position FLIR.

3. An experimental evaluation of the time required to lock onto a target with an imaging seeker system using a ground-stabilized, slewable FLIR.

TIME AVAILABLE

One of the most critical factors in an evaluation of the feasibility of using a FLIR coupled with an imaging seeker for night attack is the amount of time available in which to complete all of the required tasks. These tasks are:

1. Visual detection of the target in the FLIR display.

2. Slewing the seeker to the target.

3. Transitioning to a display of seeker imagery.

4. Centering the target in the seeker tracking gate.

5. Enabling lock-on.

The amount of time available to do these tasks is a function of the range at which the target is first detected, the velocity and altitude of the aircraft, the field of view (FOV) and gimbal limits of the FLIR and seeker, and the minimum launch range of the weapon. In the case of a fixed-position FLIR, the time available can be determined using the nomograph in Figure 1.

$$t = \frac{H}{V}\left[\cot\left(\theta - \frac{\phi}{2}\right) - \cot\left(\theta + \frac{\phi}{2}\right)\right] \tag{1}$$

where

H = altitude, ft

V = velocity, ft/sec

θ = depression angle for a fixed FLIR

ϕ = vertical FOV for a fixed FLIR

The assumption here is that the target is within the maximum detection range when it enters the FLIR FOV.

If any four of the parameters are known, the fifth can be determined using the nomograph. For example, assume:

Aircraft altitude = 3,000 ft above ground level

Aircraft velocity = 200 knots

Fixed FLIR vertical FOV = 2.0°

FLIR depression angle = 15.0°

Then the time available is 4.6 sec as the target passes through the FOV.

A fixed FLIR is set at a fixed depression angle so the scene presented to the operator on his display appears to move from the top to the bottom of the display at a constant speed. The aimpoint of the seeker is superimposed over the FLIR display and indicated by crosshairs. When a target enters the FLIR FOV, the operator, who controls the aimpoint of the seeker with a joystick, superimposes the crosshairs over the target. This points the seeker in the direction of the target. He then transitions to the seeker imagery and centers the target in the tracking gate to enable lock-on.

FIXED VERSUS SLEWABLE FLIR

In the case of a slewable FLIR, the scene presented to the operator is the same as a fixed FLIR except when the operator is slewing it. In that case, the motion of the FLIR interacts with the motion of the aircraft. By tracking a target with a FLIR the operator can increase the amount of time available while centering the target in the crosshairs before transitioning to the seeker imagery. With the slewable FLIR, the crosshairs remain in the center of the display; the operator moves the FLIR. The slewable FLIR increases the effective FOV through which a target must pass resulting in a longer time in which to transition to a seeker for lock-on.

SERIES-OF-STILLS MODE

A special case of the slewable FLIR capability is the series-of-stills (SOS) mode. In this mode the motion of the FLIR is governed by the velocity and altitude of the aircraft so that the FLIR is ground-stabilized. As the aircraft flies over the terrain, the depression angle of the FLIR increases. The scene presented to the operator appears to be static, except that objects in it grow larger as the range decreases. When a preset depression angle is reached, the FLIR quickly returns to an upper limit where it again becomes ground-stabilized.

NOMOGRAPH COMPUTATION INSTRUCTIONS

TO FIND TIME:

1. LOCATE THE LINE CORRESPONDING TO THE DEPRESSION ANGLE OF THE FLIR. THE DEPRESSION ANGLE IS THE ANGLE FROM THE AIRCRAFT BORESIGHT LINE TO A LINE BISECTING THE FLIR FOV.

2. LOCATE THE LINE CORRESPONDING TO THE VERTICAL FOV OF THE FLIR.

3. LOCATE THE INTERSECTION OF THE ABOVE TWO LINES.

4. DRAW A STRAIGHT LINE PARALLEL TO THE HORIZONTAL FOV LINES TO THE TIME LINE. HERE, THE TIME LINE IS USED AS AN INDEX LINE.

5. DRAW A STRAIGHT LINE FROM THE TIME LINE THROUGH THE FLIGHT PARAMETER LINE INTERSECTING IT AT THE GIVEN AIRCRAFT VELOCITY TO THE INDEX LINE.

6. DRAW A STRAIGHT LINE FROM THE INDEX LINE THROUGH THE FLIGHT PARAMETER LINE INTERSECTING IT AT THE GIVEN AIRCRAFT ALTITUDE TO THE TIME LINE. THIS COMPLETES THE PROBLEM.

TO FIND ANY VALUE IT IS NECESSARY TO KNOW SIX OF THE SEVEN INTERSECTION POINTS.

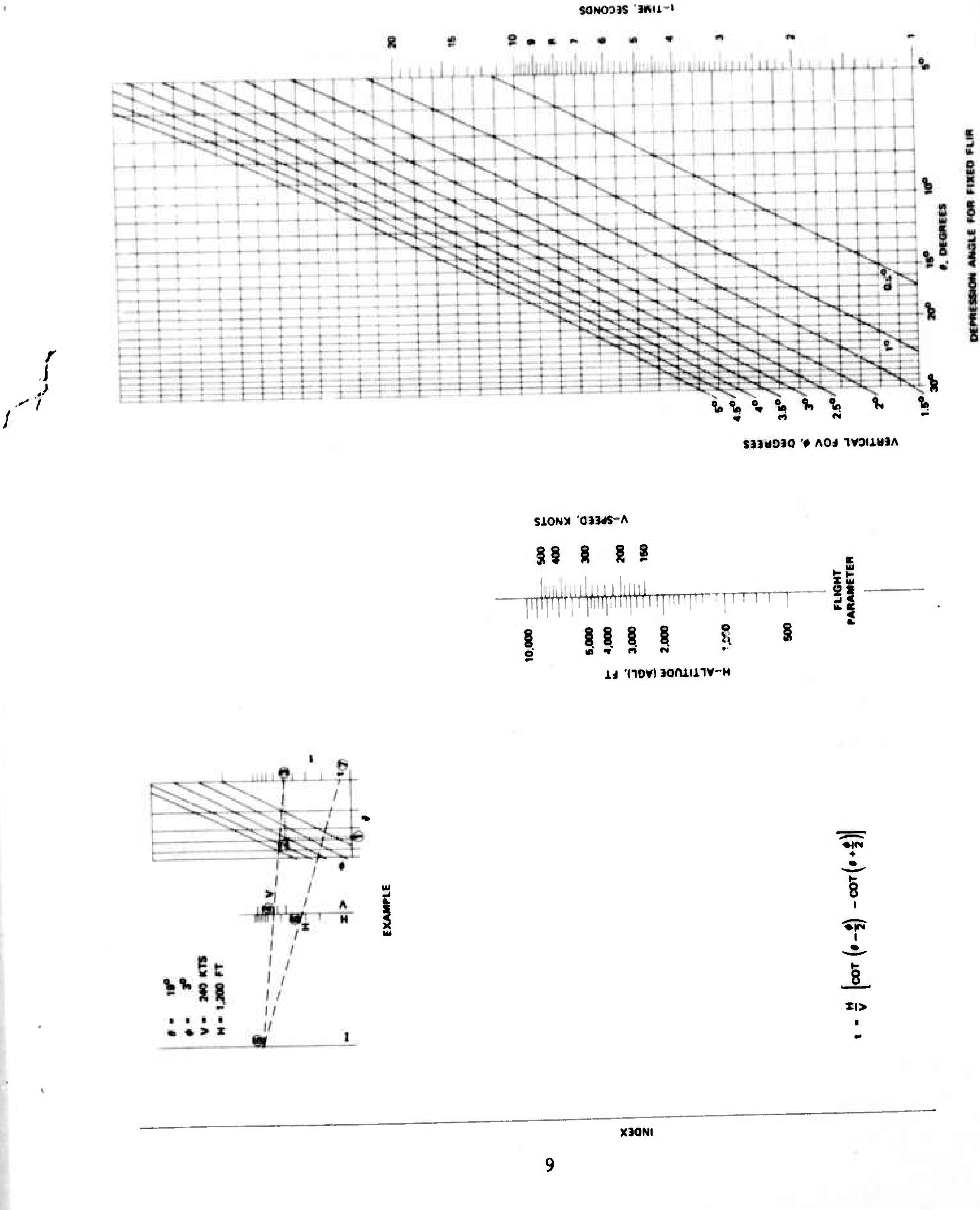
1. LOCATE ALL GIVEN VALUES ON THEIR CORRESPONDING SCALES.

2. LOCATE ALL POSSIBLE INTERSECTIONS BOTH BEFORE AND AFTER THE MISSING VALUE, IF APPLICABLE.

3. THE MISSING VALUE CAN BE LOCATED BY FINDING THE INTERSECTION OF THE VALUES IMMEDIATELY BEFORE AND AFTER THE MISSING VALUE.

4. THE DEPRESSION ANGLE CAN BE DETERMINED BY WORKING BACKWARD FROM STEP 6 ABOVE.

FIGURE 1. Nomograph.


t–TIME, SECONDS
DEPRESSION ANGLE FOR FIXED FLIR
θ, DEGREES
VERTICAL FOV φ, DEGREES
V–SPEED, KNOTS
FLIGHT PARAMETER
H–ALTITUDE (AGL), FT
θ = 18°
φ = 3°
V = 260 KTS
H = 1,200 FT
EXAMPLE
INDEX
t = H/V [cot(θ − φ/2) − cot(θ + φ/2)]

One concern about stabilizing on one area of ground is that some sections of ground may be skipped. However, the SOS mode can be used without skipping over any ground. At small depression angles the "footprint" viewed by the FLIR is very elongated. As the aircraft travels forward the FLIR "footprints" overlap. The amount of overlap (or ground skipped, G) can be determined by using Equation 2.

$$G = V\left(t_{DUR} + t_r\right) - H\left[\cot\left(\theta - \frac{\phi}{2}\right) - \cot\left(\theta + \frac{\phi}{2}\right)\right] \tag{2}$$

where

V = velocity, ft/sec

H = altitude, ft

tDUR = duration of one still, sec

t_r = time required for FLIR to return to upper gimbal limit, sec

θ = initial depression angle (shallowest)

ϕ = FLIR vertical field of view

It should be noted that, as the aircraft approaches the "footprint" on which the FLIR is stabilized, the objects in the FOV appear larger but the "footprint" grows smaller. Consequently, the overlap, if any, decreases during the approach (or the ground skipped increases). This complicates matters if a target enters the FLIR FOV near the edge of the display. In that case it may disappear from the display before the FLIR completes a still. If terrain is skipped, the target will not reenter the FOV; if terrain is duplicated, it may reenter at the bottom of the display on the next cycle. Nevertheless, if the target is immediately detected, the operator can manually control the FLIR in order to prolong his observation time.

TIME REQUIRED

Once the distribution of the times available to complete the target acquisition and weapons release tasks is known, it can be compared with a distribution of the times required to do the tasks in order to predict the probability of a successful weapon release. The amount of time required and the percentage of targets reacquired by the seeker after transitioning from the FLIR have been studied for both fixed and ground-stabilized/slewable FLIR system. (The slewable FLIR is discussed in the next section of this report.)

As described previously, the amount of time available (or the amount of time the target is in the FOV) to an operator of a fixed-position FLIR is dependent on the aircraft's altitude and velocity and the FLIR's FOV and depression angle. Burge and Craig conducted a simulation experiment[1] to determine an operator's ability to reacquire targets in an imaging seeker given various lengths of time the target remained in the FOV of a fixed FLIR. In addition, an alignment error of 3 mils was sometimes introduced between the FLIR and seeker in order to determine its effect on the operator's performance. The time required by the target to pass through the FOV for the simulated aircraft and system parameters are shown in Table 1.

TABLE 1. Times Target Remained in 1.5° x 1.5° Field of View.

Depression angle, deg	Time in FOV, sec			Slant range, nmi
	Velocity, knots			
	250	350	450	
14	6.63	4.73	3.68	2.72
16	5.02	3.58	2.79	2.39
20	3.19	2.28	1.77	1.92

[1] Naval Weapons Center. *FLIR Display Transition Experiment*, by Carol J. Burge and George L. Craig. China Lake, Calif., NWC, February 1974. (Technical Note 4011-18, publication UNCLASSIFIED.)

In the Burge and Craig study, the operator was required to search his display while a moving image of the ground passed through it (top to bottom). When he visually acquired the target in the display he slewed a set of crosshairs with a joystick, superimposing them over the target. The line of sight of the simulated seeker was also slaved by the joystick and indicated to the operator on the display by the crosshairs. When the crosshairs were superimposed over the target he immediately switched the display on the cathode ray tube (CRT) to the seeker imagery. He then reacquired the target by centering it in the seeker FOV.

A summary of the results of the Burge-Craig experiment is presented in Table 2. An interesting result was that, given less time (the target passed through the field more quickly), the subjects performed the tasks more quickly, up to a limit. The data indicated, in general, that for a 75% probability of reacquiring and tracking a target long enough to lock on, the target must remain in the FOV for a minimum of about 3 seconds. An average of 0.7 second of this time is due to transitioning from the FLIR to the seeker. In this experiment a FLIR/seeker misalignment resulted in shorter transition times, since it always occurred in the direction the target would travel on the display.

TABLE 2. Summary of Burge and Craig Data.

Time in FOV, sec	Time to switch from FLIR to seeker, sec	Percent targets reacquired	Time to reacquire, sec	Time on target, sec
1.77	0.8	48	0.3	0.1
2.79	1.2	93	0.6	0.4
3.68	1.2	82	0.7	0.4
2.28	0.9	73	0.4	0.1
3.58	1.3	96	0.7	0.7
4.73	1.3	98	0.9	0.7
3.19	1.2	93	0.6	0.6
5.02	1.6	100	1.1	1.0
6.63	1.6	100	1.0	1.7

DISPLAY TRANSITION EXPERIMENT-SLEWABLE FLIR

A new simulation experiment was conducted using a simulated FLIR system that was ground-stabilized and slewable. It was operated in the SOS mode. The operator's tasks in this experiment were to search a "still" FLIR display of the ground for the target, disable the SOS mode upon target detection, and then center the target in the display. He would then switch to the seeker imagery which was displayed on the same CRT and recenter the target, whereupon he would squeeze the joystick trigger to enable lock-on.

Care must be taken when comparing these data to that of Burge and Craig, since their data relate to a system with a fixed-position, nonslewable FLIR where the target remained in the FLIR FOV a fixed amount of time. In this study, with a slewable FLIR, the amount of time the target remained in the FOV varied, since the target could be manually tracked by the operator.

OBJECTIVE

The objective of this study was to obtain estimates of the amount of time required to accomplish the tasks outlined above, given a slewable, ground-stabilized FLIR.

It was hypothesized that these measures would be affected by differences in resolution between the FLIR and the seeker, the density of the background clutter surrounding the target, and the size of alignment errors between the FLIR and the seeker. These variables were studied in two segments of an experiment.

EXPERIMENTAL CONDITIONS

In the first segment of the experiment the background clutter density and the FLIR/seeker misalignment were varied. Three types of terrain were "flown over," each with a fairly uniform density of clutter objects. They were subjectively judged to be of high, medium, and low clutter density. Two levels of misalignment were tested in which the lines of sight of the FLIR and seeker diverged either 0.5 or 0.75 deg. The direction of the divergence of the seeker LOS from the FLIR LOS was varied randomly in a 360-deg circle around the FLIR LOS.

In this first experimental segment only one FLIR/seeker resolution ratio was tested (values are given under "Apparatus"). Therefore, each subject was presented, in his series of test trials, with one FLIR resolution level, one seeker resolution level, three clutter density levels, and two misalignment levels. The order of the presentations of clutter and misalignment was partially counterbalanced. A summary of the conditions presented to each subject is shown in Table 3.

TABLE 3. Experimental Conditions (Resolution Ratio Was 1.5).

Background clutter density	Alignment error, deg 0.5	Alignment error, deg 0.75
Low	S_1	S_1
Medium	S_1	S_1
High	S_1	S_1

The results of this segment of the experiment (presented in detail under "Results") indicated that the clutter densities tested had no effect on the task times or probabilities of lock-on. In addition, since alignment errors could be compensated for in advance, they had no effect either. However, there were indications that changing the difference between the resolution of the FLIR and that of the seeker might have a considerable effect on the task times. Therefore, a second segment of this experiment was conducted where two additional resolution ratios were tested. The data from the first segment were included in the analyses where conditions matched. The resolution of the FLIR was held constant in all cases; the resolution of the seeker was varied so that the ratio (the FLIR resolution over the seeker resolution) was 1.5, 3 or 5. Each subject was presented with only one of the ratios. Three groups of three subjects were used.

Each subject in the second segment was also presented with two levels of background clutter density (high and low) and one level of FLIR/seeker misalignment (0.75-deg). The order in which the clutter densities were presented was partially counterbalanced. The direction in which the misalignment occurred was randomized. A summary of the conditions presented to each subject is shown in Table 4.

The time required for the completion of a task was used as the dependent measure of the conditions tested. Each task was timed separately, starting from the conclusion of the preceding task. The total time required was the sum of the task times from locating the target to enabling lock-on. The subjects received eight practice trials followed by 16 experimental trials.

TABLE 4. Experimental Conditions.

Background clutter densities	Resolution ratio		
	1.5	3	5
Low	S_1	S_2	S_3
High	S_1	S_2	S_3

SUBJECTS

Nine naval aviators served as subjects for this study. All of the aviators had experience in single-place A-7 or dual-place A-6 aircraft. Four of the aviators were bombardier/navigators, five were pilots. They ranged in experience from having had 900 to 2,800 flight hours. All but one of the subjects had flight experience with a night attack type system which employed a FLIR device.

APPARATUS

Terrain Model

The terrain model was a 2.44 by 6.10 meter, three-dimensional, 1000:1 scale model. It contained numerous trees and shrubs that could be relocated as desired and varied in color from light to dark greens, browns, and yellows. The entire model moved on rails so that, when viewed with a fixed sensor, an aircraft flight could be simulated. A speed control that enabled the velocity of the terrain model to be varied from a simulated 0 to 700 knots was situated in an adjacent console.

Two test tracks were prepared on the model over which the sensors would "fly." One track consisted of rolling hills up to 100 meters high with heavy ground cover approximately 1 meter in depth. Trees, shrubs, rocks, wood clutter, and small buildings were arranged along the track so that, in appearance, the terrain resembled moderately heavily foliated foothills. The other track was virtually flat and contained no trees, shrubs, or rocks. Ground cover, approximately 0.5 meter thick was scattered sparsely over the ground in two or three places. The terrain resembled a desert. A dirt road, a simulated 3 meters wide, ran the length of each ground track. It was a gently winding road and was in view during the entire run.

FLIR/Seeker

The FLIR and the seeker were both simulated by two Sony model 3260 video cameras. The horizontal resolution of the two cameras was measured using the square-wave wedges on a RETMA pattern. The resolution of the simulated FLIR was 400 TV lines per raster height. The resolution of the simulated seeker was degraded by reducing the focus electronically to 270 lines per raster height (1.5:1 ratio with FLIR), 130 lines (3:1 ratio), and 80 lines (5:1 ratio).

The FOVs of the two sensors were identical--2.0 deg wide by 1.5 deg high. Each camera was equipped with a 6-inch lens. A 1.0-deg or 1.5-deg wedge of optical quality glass was used in front of the seeker lens during each trial to diffract the video imagery and create a misalignment between the two sensors of either 0.5 or 0.75 deg, respectively.

Sensor Gimbal System

The two video cameras were situated on a pan and tilt platform (see Figure 2). Also attached to both the platform and the camera lenses was a mechanical device that was driven by the tilting motion of the platform. The device was geared to change the focus of the two camera lenses in order to maintain correct optical focus on the ground despite a change in slant range from the sensors to the ground. In addition, this device changed the alignment of the two cameras as a function of elevation in order to correct for parallax. When properly positioned the two cameras would view the same area of the ground at all depression angles and stay in optical focus.

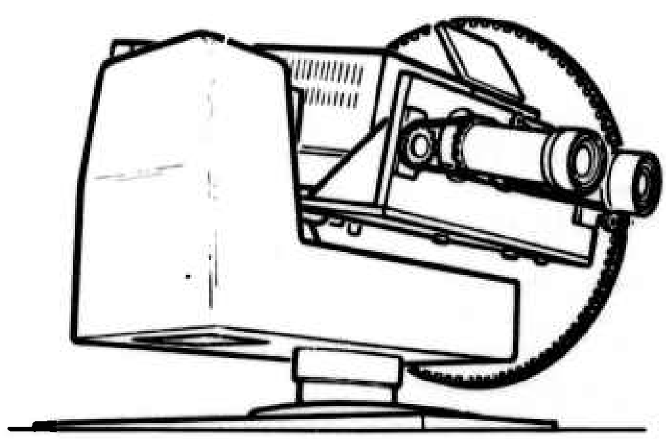


FIGURE 2. The Pan and Tilt Gimbal System With Two Cameras.

The pan and tilt table operated either in an automatic SOS mode or was driven by a manual thumb controller. In the SOS mode the tilt platform dipped from an upper limit of -14 deg below the horizontal to a lower limit of -15 deg below the horizontal. The speed at which the platform dipped could be adjusted in both initial rate and acceleration in order to match the motion of the terrain as it passed underneath. The imagery provided by the sensors mounted on the tilt platform thus appeared to be ground-stabilized. When the platform reached the lower elevation limit in the SOS mode, it automatically returned to the upper limit and started to dip again. In this way, a series of essentially static images was provided to the system operator. The only motion detectable in the imagery was due to the shortening range between the sensors and the ground during presentation of a single image. In this case the area of the ground being viewed decreased in size and the objects in the FOV increased in size.

The manual thumb controller, located on the stick grip, was continuously operational. The subject could override the constant downward motion of the tilt platform and/or control the pan direction with the thumb controller.

The right-hand, press-on/press-off button on the stick grip controlled the SOS mode. Depressing this button disabled the lower limit of the SOS mode and permitted the apparently ground-stabilized tilt platform to decline below -15 deg from the horizontal. A legend light on the instrument panel labeled "SOS" indicated that the SOS mode was operational when lit. When the SOS mode was not selected the thumb controller remained operational.

Simulation

The following were the simulated flight and system parameters.

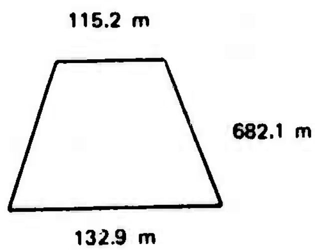
Simulated aircraft:

Altitude, ft	4,000
Velocity, knots	250

Sensor system:

FLIR FOV, deg	2.0 wide x 1.5 high
Seeker FOV, deg	2.0 wide x 1.5 high
Upper elevation limit	14 deg below horizontal
Lower SOS mode elevation limit	15 deg below horizontal
Lower manual slew mode elevation limit	35 deg below horizontal
Duration of one still image, sec	7
Sensor/seeker slew rate	variable, depending on force exerted on thumb controller, up to approximately 7 deg/sec

Simulated ground area viewed by sensors at 14.5 deg below horizontal:



Operator's Controls and Displays

The subjects were provided with a single TV monitor, on which either the FLIR or the seeker imagery was displayed, legend lights, and a four-function stick grip. The video imagery was displayed on a Conrac 525-line, 9-inch diagonal, closed-circuit TV monitor. Superimposed over the simulated FLIR imagery was a crosshair approximately 2 TV lines thick that was generated by a Shintron Crosshair Generator. A second generator was used to superimpose a 3-mrad white square over the seeker imagery to simulate a tracking gate. The solid white tracking gate partially obscured the area over which it was superimposed.

Four legend lights surrounded the display on the instrument panel. They indicated the status of the SOS mode (on-off), which sensor was selected (FLIR or SEEKER), and LOCK ENABLE. An illustration of the displays on the instrument panel is presented in Figure 3.

The stick grip was located on the right-hand console of the simulated cockpit. On the grip was the thumb-controller, which controlled the position of the pan and tilt platform on which the sensors were located. To the right of the thumb-controller was a push-on/push-off button, which was used to engage or disengage the SOS mode. To the left of the thumb-controller was another push-on/push-off button, which was used to select the FLIR or seeker. At the start of each trial pass, the SOS mode was engaged and the FLIR imagery was selected. Thereafter, one press of the right button disengaged the SOS mode and one press of the left button selected the seeker imagery. In the front of the stick grip was the trigger. Pulling the trigger caused the LOCK ENABLE light to illuminate, although it had no other effect on the system. The two buttons and the trigger, when depressed, sent a signal to a strip chart recorder. An illustration of the stick grip is presented in Figure 4.

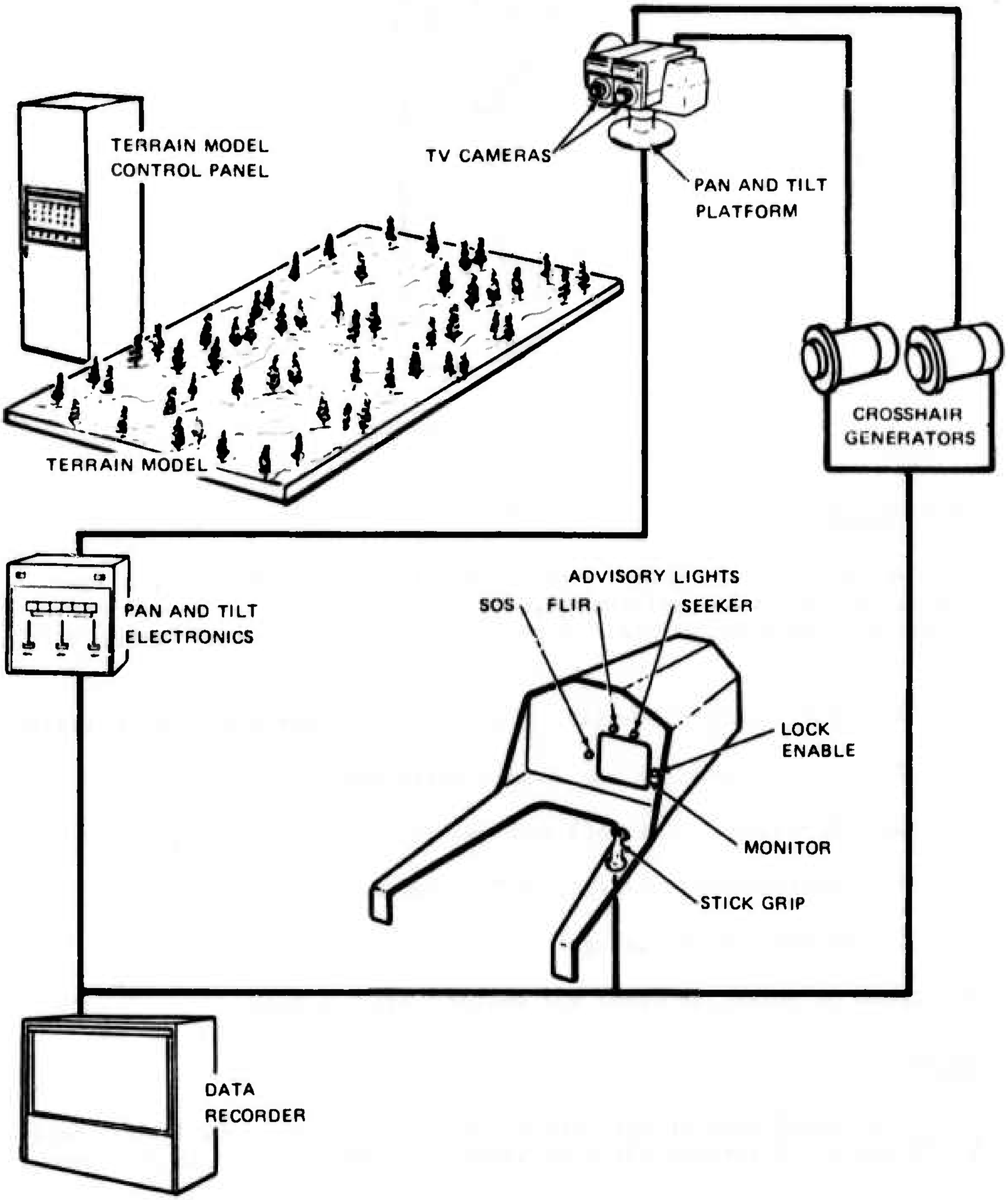


FIGURE 3. The Experiment Setup.

FIGURE 4. Stick Grip.

Data Recorder

A Sanborn strip chart recorder was used to produce a time line record of the tasks performed during a trial pass. The record provided an indication of the following events that occurred during each trial:

1. The return of the tilt platform to the upper elevation limit.

2. Any operation of the thumb-controller.

3. Depression of the SOS mode button.

4. Depression of the FLIR/SEEKER button.

5. Squeeze of the trigger.

The speed at which the paper was emitted was 5 mm/sec.

Target

The target used in this experiment was a single 1000:1 scale-model 2 1/2-ton truck painted white to simulate a "hot" target in IR imagery.

Lighting

Twenty, 4-bulb, 40-watt flourescent fixtures were lined up along two rows that ran 12 meters of the length of the terrain model track. They were situated 1.5 meters above the terrain model.

PROCEDURE

When the subject arrived he was seated in the simulated cockpit facing the display. A tape-recorded set of instructions was played, explaining the purpose of the study, the characteristics of the system, its modes of operation, and the task the subject was to perform. While the instructions were given, the subject was shown the test imagery and allowed to practice operating the switches and controls. Following the instructions, questions were answered regarding the system's operation while practice continued. In addition, the subject was given a preview of what the target looked like on the terrain in the imagery. It was not the intention of this study to make the target difficult to detect initially, so the subject was well prebriefed.

After eight practice trials, the subject was familiar with the appearance of the target and the operation of the system. Test trials were presented and the results were recorded.

The procedure followed by the subject during a trial pass was as follows: As the system "flew" over the terrain, the subject was presented with a series of essentially still images of the terrain. Five stills were presented during each "flyover." The subject scanned each still until he located the target. The target was always located on or near a narrow road that ran the length of the ground track. The subject was instructed to keep the road near the center of the FOV by using the thumb controller to slew the FLIR. However, he was instructed not to slew the FLIR along the road by holding it in a fixed position (it was to remain ground-stabilized for the 7-sec period). When the target was located, the subject depressed the SOS mode button immediately to disable the lower limit of the FLIR. He then attempted to slew the FLIR toward the target using the thumb controller so that the crosshairs were superimposed over it. This strategy was employed to preclude the probability that a misalignment of the FLIR and seeker would cause the target to shift out of the FOV when the operator transitioned from the FLIR to seeker imagery. The subjects were instructed that it was not necessary to superimpose the crosshairs over the target exactly; it was suggested they use their own judgment based on their experience with the FLIR/seeker misalignment to determine the accuracy required. When the subjects had accomplished this task, they were instructed to depress the FLIR/seeker button to transition to the seeker imagery. They then slewed the seeker toward the target to superimpose the tracking gate over it. As soon as the target entered the gate, the subject depressed the LOCK ENABLE button. This ended the trial.

The experimenter's tasks during the test runs included situating the target along the ground track with the correct clutter density, changing the lateral position of the "aircraft" so it would "fly" over the correct track, adjusting the misalignment between the FLIR and seeker, starting the terrain model, turning on the operator's monitor, and starting the strip chart recorder. At the conclusion of each trial pass, the subject's video display was blanked while the terrain model was stopped and the target was relocated.

After all the test trials were completed, the subject was questioned regarding his assessment of the simulation, the system, and his performance.

RESULTS

The normalized cumulative frequencies of the task times are shown in Figure 5. It can be seen that reducing the resolution of the seeker increases the amount of time required to lock on. The data in Table 5 indicate, as expected, that this increase in time required was due to longer reacquisition times resulting from the degraded seeker imagery.

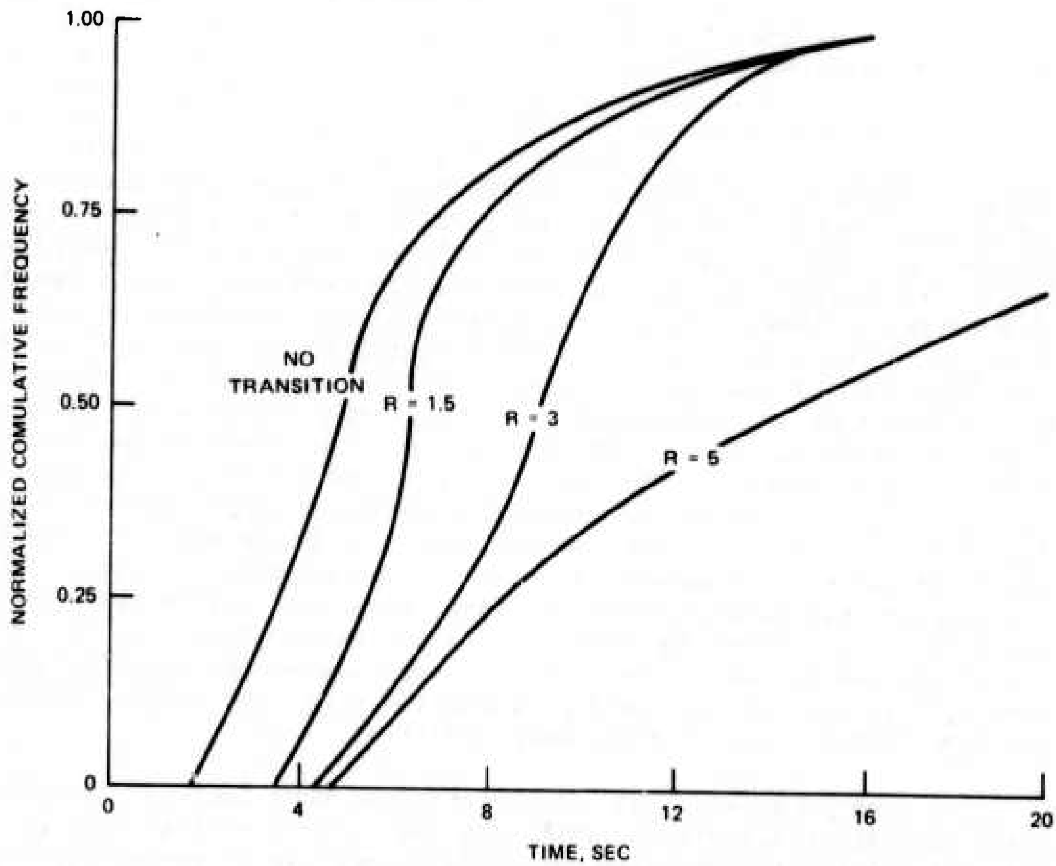


FIGURE 5. Normalized Cumulative Frequencies of Total Tasks Completed Within T for Each Resolution Ratio (R) Tested. Also included are data for tasks without transition.

TABLE 5. Mean Task Times Combined Across Background Density, Alignment Error, and Subjects.

Resolution ratio	Mean task time, sec[a]		
	T_1 (Disable AUTO)	T_2 (Switch to SEEKER)	T_3 (LOCK-ENABLE)
1.5	2.5	1.6	2.7
3	2.6	3.6	4.1
5	2.2	3.9	7.4

[a] T_1 measured from entry of target into FOV.
T_2 measured from T_1.
T_3 measured from T_2.

Figure 5 also presents the time required to initiate target tracking with the FLIR, but without transition. This time included the time required to locate a target in the FOV, slew the FLIR to center the target in a tracking gate, and depress a LOCK-ENABLE trigger. The time required to operate a system with a nonimaging seeker may closely approximate this curve. The data represented by this curve were taken from the times required to complete all operations up to the transition task in this experiment. These same tasks would be required for systems both with or without an imaging seeker.

Figures 6 and 7 translate the data into the distances an aircraft would travel while an operator achieves a lock-on with a 50 and 75% probability. The minimum detection range necessary to allow sufficient time to complete a lock-on with a 50 to 75% probability can be determined by adding the minimum launch range of the missile to those figures.

The percentage of reacquisitions as a function of resolution ratio is presented in Figure 8. When the resolution of the FLIR and seeker were nearly equal, reacquisition of the target with the seeker always occurred. As the resolution of the seeker was decreased to one-fifth of the FLIR, the mean percent of reacquisitions dropped to about 79. The variability among operators increased dramatically; at a resolution ratio of 5, the individual operators had 100, 81, and 56% reacquisitions.

An analysis of variance was performed on the total tasks times (resolution ratio x clutter). The results indicated that there were no differences in task times as a result of differences in background clutter. There was, as expected, a significant increase ($P < 0.01$) in the time required for lock-on as a result of decreasing the seeker resolution.

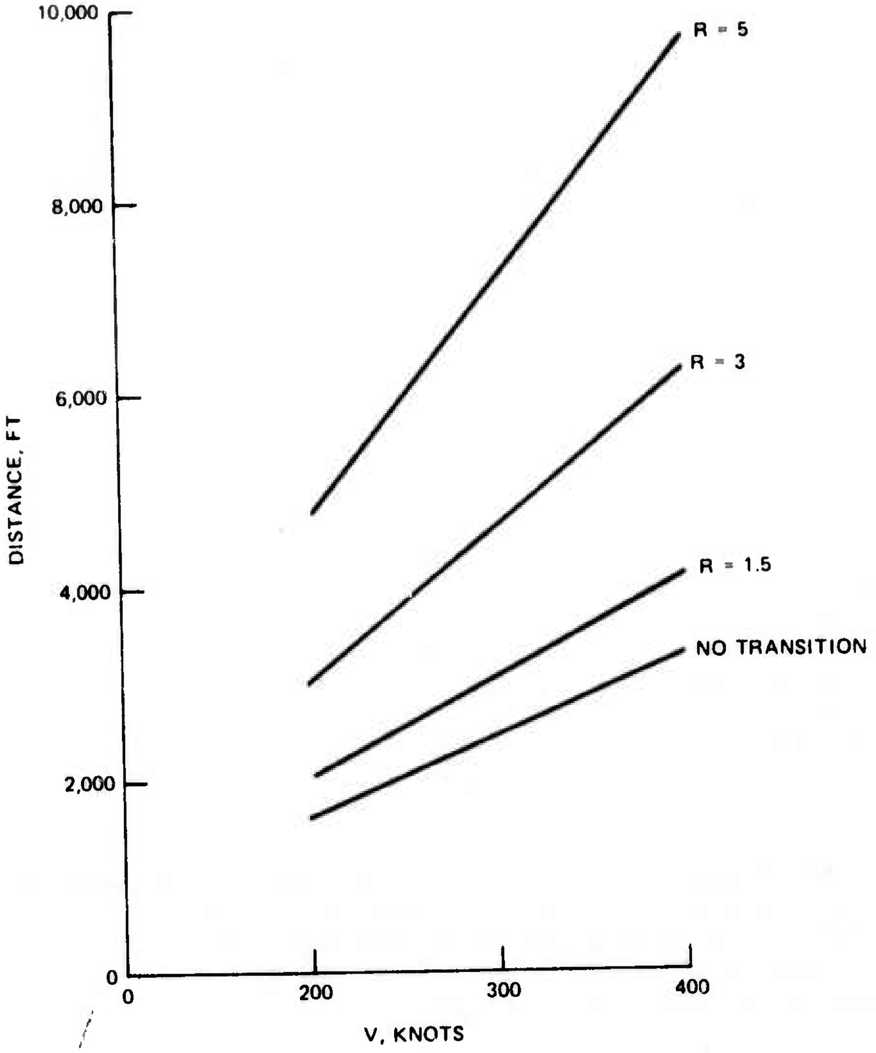


FIGURE 6. Distance Aircraft Traveled During Time Required for 50% Probability of Lock-on as a Function of Velocity and Resolution Ratio.

Three analyses of variance (misalignment x clutter) were performed on the data for the three task times (T_1, T_2, and T_3). These results pertain only to the case where the FLIR/seeker resolution ratio was 1:5. In these cases there were no significant differences due to the density of the background clutter or to the amount of the FLIR/seeker misalignment. Comments by several of the subjects, in fact, indicated that background clutter was a help, rather than a hindrance, in relocating a target, because it provided geographical cues to the target location. At least one subject also checked the misalignment at the start of a trial rather than having it come as a surprise. This strategy could be employed routinely during operation of a FLIR/seeker system, further reducing the potential misalignment problem.

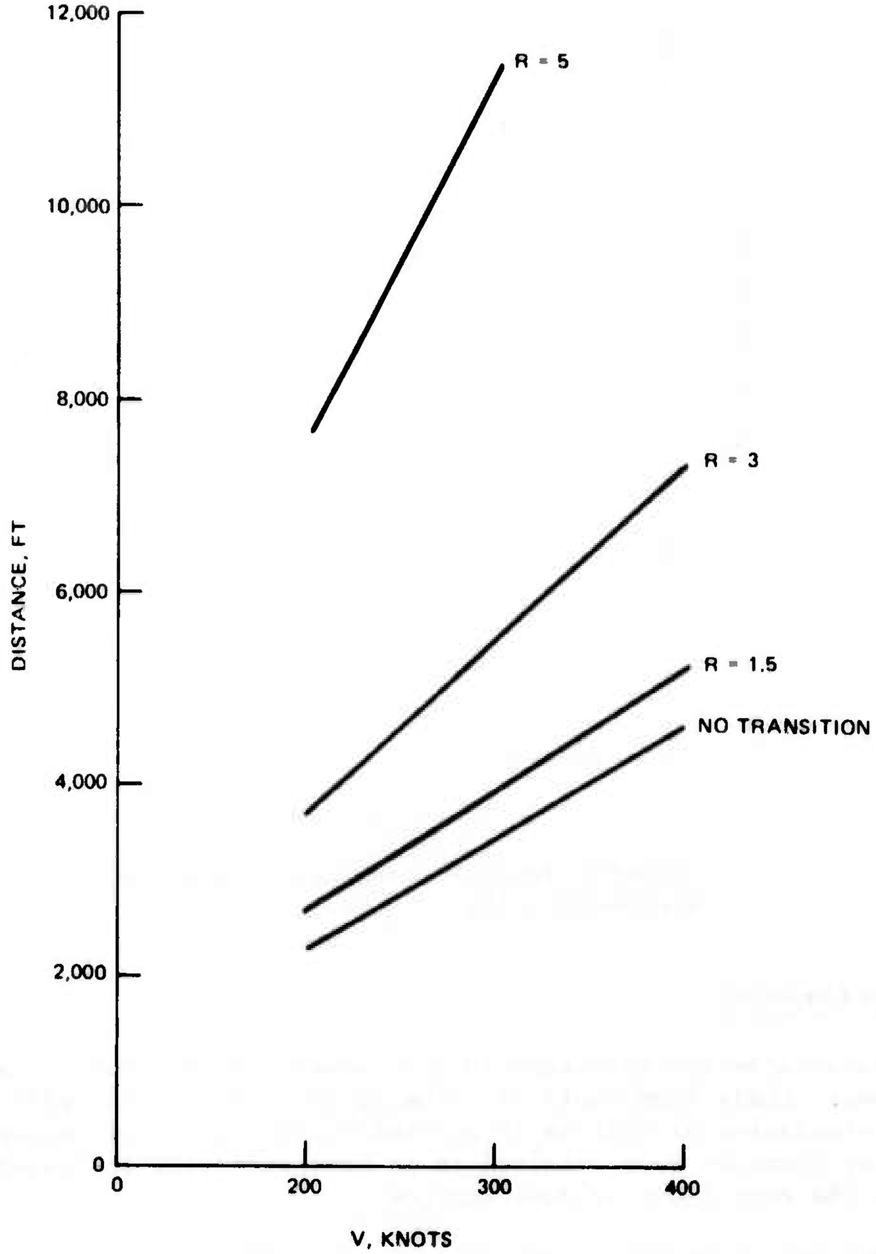


FIGURE 7. Distance Aircraft Traveled During Time Required for 75% Probability of Lock-on as a Function of Velocity and Resolution Ratio.

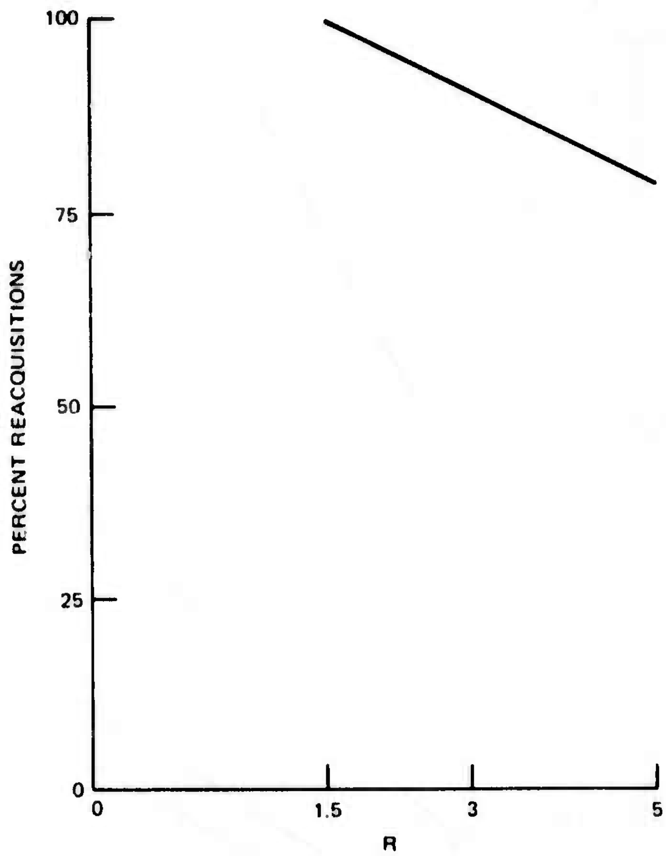


FIGURE 8. Percent Reacquisitions as a Function of Resolution Ratio (R).

Operators Comments

Inasmuch as the simulator in this study was operated by experienced aircrewmen, their commentary is valuable in assessing the effectiveness of the simulation as well as in understanding their performance. The following comments were obtained in an oral interview following completion of the experiment by each subject.

"What did you think of the simulation quality?"

> "Overall - Good. Need two fields of view or zoom. Having the FLIR and seeker misaligned is very realistic, but sometimes the target doesn't even reappear in the [seeker] FOV in a real system. Need more target types--and also moving targets. Target types should be changed during experiment. Need more vertical buildup on terrain model. It would be good to try the experiment with water background. Slew stick was not likely to be the operational design."

"Resolution was too good on seeker and FLIR [this subject saw seeker with resolution closest to that of FLIR]. Didn't like seeker tracking gate--used to open gate."

"Thumb controller was too jerky. It was difficult to make small adjustments."

"Very realistic simulation. I'm a pilot [A-6] and for me the stick is on the wrong side. I would prefer a slew stick rather than a thumb controller. A 'coolie cap' would be better as a thumb controller."

"Pretty good realism. I didn't know I was flying over different roads. Thumb control should have looser tension. Prefer 'coolie cap'."

"How would you assess the ground-stabilized mode (Series-of-Stills)?"

"Don't remember it . . . never really aware it was doing that."

"When you're inspecting the target you can't really gauge when [the FLIR] will flip up."

"Didn't like S-O-S because time was lost due to video blur. Also, I didn't like to wait when I was done searching a piece of ground."

"I like S-O-S better than snowplow because you have more time for inspecting the target. You don't lose your bearings if you wait for closer inspection."

"I liked it, but I'd want to compare it directly with snowplow to see if it's better. It was good to sit and look at the picture. Snowplow's good when the target is on the road, but when it's off the road S-O-S might be better."

"Didn't like S-O-S because the jumping made me uneasy. I kept thinking I was missing something. I never got time to search the bottom well enough."

"I prefer snowplow . . . probably 'cause I'm not used to [S-O-S]."

"What is your evaluation of the switchology that was used?"

Most of the comments were concerned with the thumb controller. Two subjects mentioned that they preferred a coolie cap to the cylinder type controller. Three subjects commented that the controller was too sensitive for 'fine tuning.' The pilots generally were confused by the use of a B/N control/cursor stereotype (where pushing the thumb controller down caused the cursor to close in range). However, after several practice trails they were able to operate the controller properly.

"Were you troubled by the FLIR/seeker misalignment?"

"This didn't bother me towards the end. I switched back and forth between FLIR and seeker at the start of each run so I'd know what the alignment was."

"The misalignment is worse when it's towards you (down) because then you have to chase it. When it's away from you (up) you can let it come to you."

"Misalignment is a big problem [when the seeker resolution is poor] because you can't find the target again."

"It wasn't too bad because you can look for geographical cues to relocate the target."

"I looked for a landmark near the target and when I switched to the seeker I just [relocated] the landmark first."

DISCUSSION OF RESULTS

The results of this study indicated that misalignment between the FLIR and the seeker (when the misalignment is not greater than one-half the FOV) had little effect on the time required under the conditions of clutter tested. This is probably especially true if the system operator checks out the amount of the misalignment in advance as one subject in this study did. In this way, the misalignment can even be used to advantage by reducing the amount the FLIR needs to be slewed. That is, the target can be positioned in the FLIR display, off-center, in such a manner that it will be under the seeker tracking gate after the imagery is switched. This tactic may well deserve further investigation.

It was originally hypothesized that increasing the amount of background clutter would make it more difficult to reacquire the target in the seeker display. The data suggest, in fact, that increasing the clutter has no effect on the time or the percentage of reacquisitions. Pilot comments indicated that background clutter merely provided geographical cues useful in relocating the target. In this experiment the target was always located near a road. That cue, together with nearby trees, made the target apparently easy to reacquire. In some cases, however, when the road was almost invisible and the target was not adjacent to trees, the subjects seemed to have more difficulty. If, in reality, the *absence* of clutter and clues *increases* the time required for lock-on and decreases the probability of reacquisition, a low-resolution system may be difficult to use against targets at sea.

Pilot comments suggested that there was no consensus on the utility of the SOS mode. In general, the criticism appeared to be due to two factors: unfamiliarity with the mode, and the duration of the stills. Several operators, in fact, used the thumb controller to hold the FLIR in a fixed position rather than ground-stabilized so the imagery was moving in their display like a more conventional system. Some operators complained that they were unable to relate one still to the next. Favorable comments suggested, on the other hand, that the long duration of the still was appreciated by several subjects.

Under very poor viewing conditions or with low-resolution sensors, the ground-stabilized mode is useful in reducing further video blur due to aircraft motion. A careful investigation of performance with the SOS mode compared to the snowplow mode with unbiased operators is required to evaluate fairly the potential of the ground-stabilized mode. One of the parameters that should be varied is the duration of a single still.

The data obtained during this experiment can be useful both for assessing the probability of locking onto a target given current system specifications, and for designing future systems with a requirement for a given probability of lock-on. However, in order to assess the capability of any system it is necessary to know how much time is available, as well as how long it takes to perform the required tasks. The amount of time available is a function of the maximum detection range, the minimum launch range, the aircraft's flight parameters, the sensor characteristics such as FOV, gimbal limits and resolution, and the operator's workload.

The data presented here demonstrate that it does, indeed, take longer to use an imaging seeker than a nonimaging seeker simply because an additional task is necessary. For example, given a 75% probability of lock-on at a velocity of 350 knots, with FLIR/seeker resolution ratio of about 2.5 to 1, the aircraft travels about 5,800 ft between target detection and lock-on, versus 4,000 ft where transition to the seeker is not required. However, what this difference means in the operational milieu can only be known when analyzed in context with the total time available.

In designing future systems, the data presented here can be used, again in context with the projected time available, to determine how much time can be spent performing the required tasks. This information can then be used to determine the minimum seeker resolution necessary to ensure the desired probability of success. However, using data such as this for prediction purposes should only be attempted for conditions similar to those that were tested.

INITIAL DISTRIBUTION

31 Naval Air Systems Command
  AIR-04 (1)
  AIR-104 (1)
  AIR-30212 (2)
  AIR-340F (1)
  AIR-360B (1)
  AIR-410 (1)
  AIR-510 (1)
  AIR-5102 (1)
  AIR-5103 (1)
  AIR-5105 (1)
  AIR-5108 (1)
  AIR-5108B (1)
  AIR-5109 (1)
  AIR-5313 (5)
  AIR-532 (1)
  AIR-5321 (1)
  AIR-5323 (1)
  AIR-533 (1)
  AIR-533B1 (1)
  AIR-533F3 (1)
  AIR-5332 (1)
  AIR-5333 (1)
  AIR-5333E2 (1)
  AIR-535 (1)
  AIR-954 (2)

3 Chief of Naval Operations
  OP-098 (1)
  OP-0982 (1)
  OP-55 (1)

1 Chief of Naval Material

3 Naval Sea Systems Command
  SEA-03 (1)
  SEA-09G32 (2)

3 Chief of Naval Research, Arlington
  ONR-211 (1)
  ONR-455 (1)
  ONR-461 (1)

1 Bureau of Medicine & Surgery (Code 513)

1 Commandant of the Marine Corps

1 Air Test and Evaluation Squadron 4

1 Air Test and Evaluation Squadron 5

1 Naval Aerospace Medical Research Laboratory, Pensacola (Code L5)

7 Naval Air Development Center, Johnsville
  Code 402 (1)
  Code 4021 (1)
  Code 4022 (1)
  Code 4023 (1)
  Code 4024 (1)
  Code 403 (1)
  Technical Library (1)
1 Naval Air Force, Atlantic Fleet
1 Naval Air Force, Pacific Fleet
1 Naval Air Test Center (CT-176), Patuxent River (SY-72)
1 Naval Avionics Facility, Indianapolis
1 Naval Electronics Laboratory Center, San Diego
6 Naval Personnel Research and Development Center, San Diego
  Code 02 (1)
  Code 03 (1)
  Code 311 (2)
  Code 312 (2)
3 Naval Postgraduate School, Monterey
  Dr. James Arima (1)
  Dr. Gary Poock (1)
  Technical Library (1)
2 Naval Research Laboratory
1 Naval Submarine Medical Center, Naval Submarine Base, New London
1 Naval Surface Weapons Center, White Oak (Technical Library)
2 Naval Training Equipment Center, Orlando
  Code 215 (1)
  Technical Library (1)
1 Office of Naval Research Branch Office, Pasadena
1 Operational Test and Evaluation Force
3 Pacific Missile Test Center, Point Mugu
  Code 1242 (2)
  Technical Library (1)
1 Office Chief of Research and Development
1 Army Armament Command, Rock Island (AMSAR-SAA)
1 Army Combat Developments Command, Armour Agency, Fort Knox
1 Army Combat Developments Command, Aviation Agency, Fort Rucker
1 Army Combat Developments Command, Experimentation Command, Fort Ord (Technical Library)
1 Army Combat Developments Command, Field Artillery Agency, Fort Sill
1 Army Materiel Development & Readiness Command
1 Army Missile Command, Redstone Arsenal
1 Army Training & Doctrine Command, Fort Monroe
1 Aeromedical Research Laboratory, Fort Rucker
1 Army Ballistics Research Laboratories, Aberdeen Proving Ground
2 Army Human Engineering Laboratory, Aberdeen Proving Ground
2 Army Materiel Systems Analysis Agency, Aberdeen Proving Ground
1 Army Mobility Equipment Research and Development Center, Fort Belvoir (Library)

1 Army Research Institute, Arlington
1 Fort Huachuca Headquarters, Fort Huachuca
2 Frankford Arsenal
2 Picatinny Arsenal
SMUPA-AD-C (1)
SMUPA-FRL-P (1)
1 Redstone Arsenal (DRXHE-MI)
1 White Sands Missile Range
1 Air Force Logistics Command, Wright-Patterson Air Force Base
1 Air Force Systems Command, Andrews Air Force Base (SDW, Roger Hartmeyer)
1 Tactical Air Command, Langley Air Force Base
1 Oklahoma City Air Materiel Area, Tinker Air Force Base
3 Aeronautical Systems Division, Wright-Patterson Air Force Base
Code AER (1)
Code RW (1)
Code XR (1)
1 Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base
1 Air Force Armament Laboratory, Eglin Air Force Base (Technical Library)
2 Defense Documentation Center
1 Director of Defense Research & Engineering (TST&E)
1 Defense Intelligence Agency
1 Applied Physics Laboratory, JHU, Laurel, Md
2 Autonetics/Rockwell International Corp., Anaheim, Ca (Human Factors Group)
5 Boeing Aerospace Company, Seattle, Wa (Crew Systems-MS 41-44)
2 Calspan Corporation, Buffalo, New York (Life Sciences Avionics Dept.)
3 Hughes Aircraft Company, Culver City, Ca (Display Systems Laboratory)
1 Human Factors Research, Inc., Goleta, Ca
1 Institute for Defense Analyses, Arlington, Va (Technical Library)
2 Vought, Incorporated, Systems Division, Dallas, Tx (Human Factors Engineering)
2 McDonnell Douglas Corporation, Long Beach, Ca (Director, Scientific Research, R & D Aircraft Division)
2 McDonnell Douglas Corporation, St. Louis, Mo (Engineering Psychology)
1 National Academy of Sciences (Vision Committee), Washington, D.C.
1 Rockwell International Corp., Columbus, Oh
2 Systems and Research Center, Minneapolis, Mn (Vision & Training Technology)
1 The Martin Company, Orlando, FL
1 The Rand Corporation, Santa Monica, Ca (Dr. H. H. Bailey)
1 University of California, Scripps Visibility Laboratory, San Diego, Ca
2 Virginia Polytechnic Institute, Blacksburg, Va (Industrial Engineering Dept)